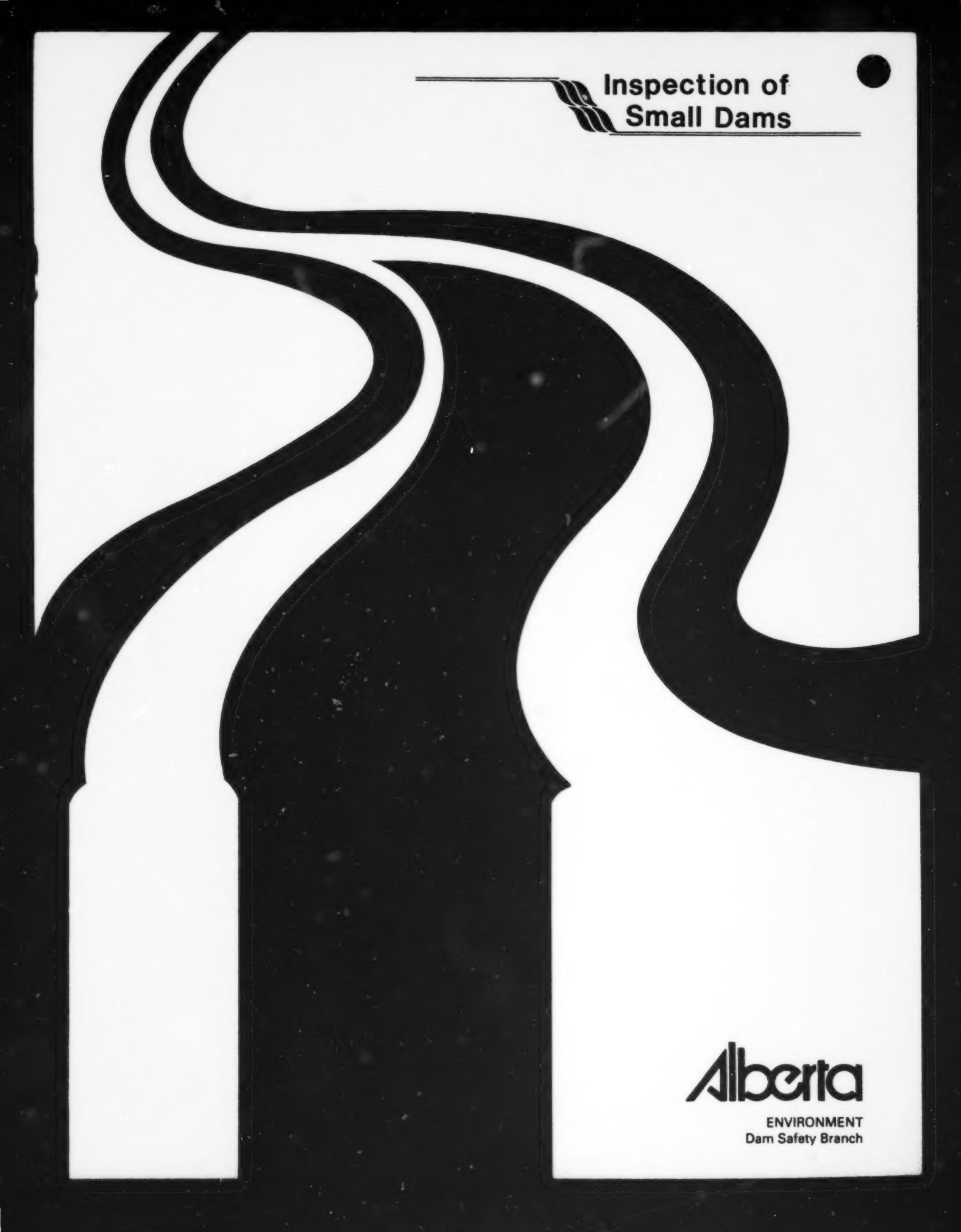
# Inspection of Small Dams



Alberta

ENVIRONMENT
Dam Safety Branch

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Revision I

# THE WATER RESOURCES ACT

# DAM AND CANAL SAFETY REGULATIONS

# INSPECTION OF SMALL DAMS

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August 1985

# THE WATER RESOURCES ACT
# DAM AND CANAL SAFETY REGULATION
# INSPECTION OF SMALL DAMS

## TABLE OF CONTENTS


| | | Page No. |
|---|---|---|
| | List of Photos | 3 |
| 1. | Introduction | 4 |
| 2. | Elements of a Dam | 5 |
| | A. General | 5 |
| | B. Main Embankment and Foundation | 5 |
| | C. Main and Emergency Spillways | 8 |
| | D. Riparian Outlets | 8 |
| 3. | Inspection Guidelines | 9 |
| | 3.1 General | 9 |
| | 3.2 Spillways | 12 |
| | 3.3 Seepage | 17 |
| | 3.4 Embankment Slides | 19 |
| | 3.5 Cracks | 22 |
| | 3.6 Erosion | 23 |
| | 3.7 Riparian Outlets | 26 |
| | 3.8 Burrowing Animals | 29 |
| | 3.9 Vegetation | 30 |
| | 3.10 Reservoir | 31 |
| | 3.11 Inspection Checklist | 32 |
| | 3.12 Inspection Report | 34 |

## LIST OF PHOTOGRAPHS


| Photo No. | | Page No. |
|---|---|---|
| 1 | Breached dam..... | 11 |
| 2 | Trash rack on a drop inlet spillway..... | 13 |
| 3 | Eroded spillway channel..... | 13 |
| 4 | Extensive erosion at the spillway resulted in the failure of the control structure..... | 14 |
| 5 and 6 | Overtopping of this dam caused extensive erosion to the downstream slope..... | 15 |
| 7 | Corrugated Steel Pipe, separated seams have exposed the backfill to erosion..... | 16 |
| 8 | Seepage marsh located immediately downstream of the embankment..... | 17 |
| 9 | Piping failure adjacent to conduit..... | 18 |
| 10 | Embankment slide on the downstream slope..... | 19 |
| 11 and 12 | Longitudinal cracks in the embankment..... | 21 |
| 13 | Displacement of the riprap has resulted in unprotected areas on the upstream slope..... | 24 |
| 14 | Eroded upstream slope..... | 24 |
| 15 | Eroded downstream slope..... | 25 |
| 16 | Well riprapped upstream slope..... | 25 |
| 17 | Well maintained downstream slope..... | 26 |
| 18 | Blocked Inlet..... | 27 |
| 19 | A bent control shaft makes this riparian outlet inoperable..... | 27 |
| 20 | Riparian Outlet. Erosion has exposed the last section of pipe which has become detached adding to the erosion problem..... | 28 |
| 21 | Tree growth on the embankment slopes is undesirable..... | 30 |
| 22 | Shrubs obscuring the embankment slopes make inspections difficult..... | 31 |

# THE WATER RESOURCES ACT
# DAM AND CANAL SAFETY REGULATION
# INSPECTION OF SMALL DAMS

## 1. INTRODUCTION

This pamphlet has been prepared by the Dam Safety Branch, Alberta Environment to provide dam owners information and guidelines for making visual safety inspections. It is aimed at the owners of dams and canals who operate their structures privately (ie. without the benefit of an organization that has professional engineers on staff). By using this pamphlet, it is hoped that these owners will be able to recognize any potential danger to their structures.

Routine inspections will enable dam owners to detect problems at an early stage, thereby minimizing the risk of serious damage. Since some problems may not be obvious during the first inspection, dams that appear in good condition should not be eliminated from an inspection program. Problems can develop or progress at any time, especially following severe storms. When a problem is detected or suspected, the owner should seek the advice of a professional engineer experienced in the design of dams. Farmers and ranchers are eligible for advice without charge from the Prairie Farm Rehabilitation Administration (PFRA).

The Dam Safety Branch, in the course of its administration of the Dam and Canal Safety Regulation, Alberta Regulation 351/78, will periodically inspect all of the dams in the province that exceed 8 metres in height or exceed 60,000 cubic metres storage.

## 2. ELEMENTS OF A DAM

### A. GENERAL

A dam is an artificial barrier which does or is capable of impounding or diverting water. Earthfill dams consist of a main embankment and may include any of the following structures; dykes, spillways, emergency spillways and riparian or canal outlets.

Throughout the province of Alberta, dams are constructed to serve various purposes: diversion, flood control, hydroelectric power, irrigation, mine tailings storage, recreation, waterfowl propagation, stockwatering, domestic and industrial water supply.

### B. MAIN EMBANKMENT AND FOUNDATION

The main embankment which is usually constructed across a natural water course, and any dykes which may be required, serve to impound water in the reservoir. The dam should be stable and designed to minimize seepage losses, control seepage and prevent wave erosion. Typical dam cross sections are illustrated in Figure 1.

Factors which affect stability include, foundation conditions, compaction of the selected fill material and adequate slopes. If a combination of ideal conditions such as a good foundation, sound fill materials and good construction supervision is available, stable slopes for a small dam may be a minimum of 3 horizontal to 1 vertical for the upstream slope and 2.5 horizontal to 1 vertical for the downstream slope.

Controlling the amount and path of seepage is essential to maintain the dam in good condition. The main aim should be to avoid concentrated seepage flows. The embankment and foundation should be as impermeable as possible. If the dam is constructed on a foundation with a relatively permeable layer, a cutoff trench backfilled with compacted impervious material is used to control seepage.

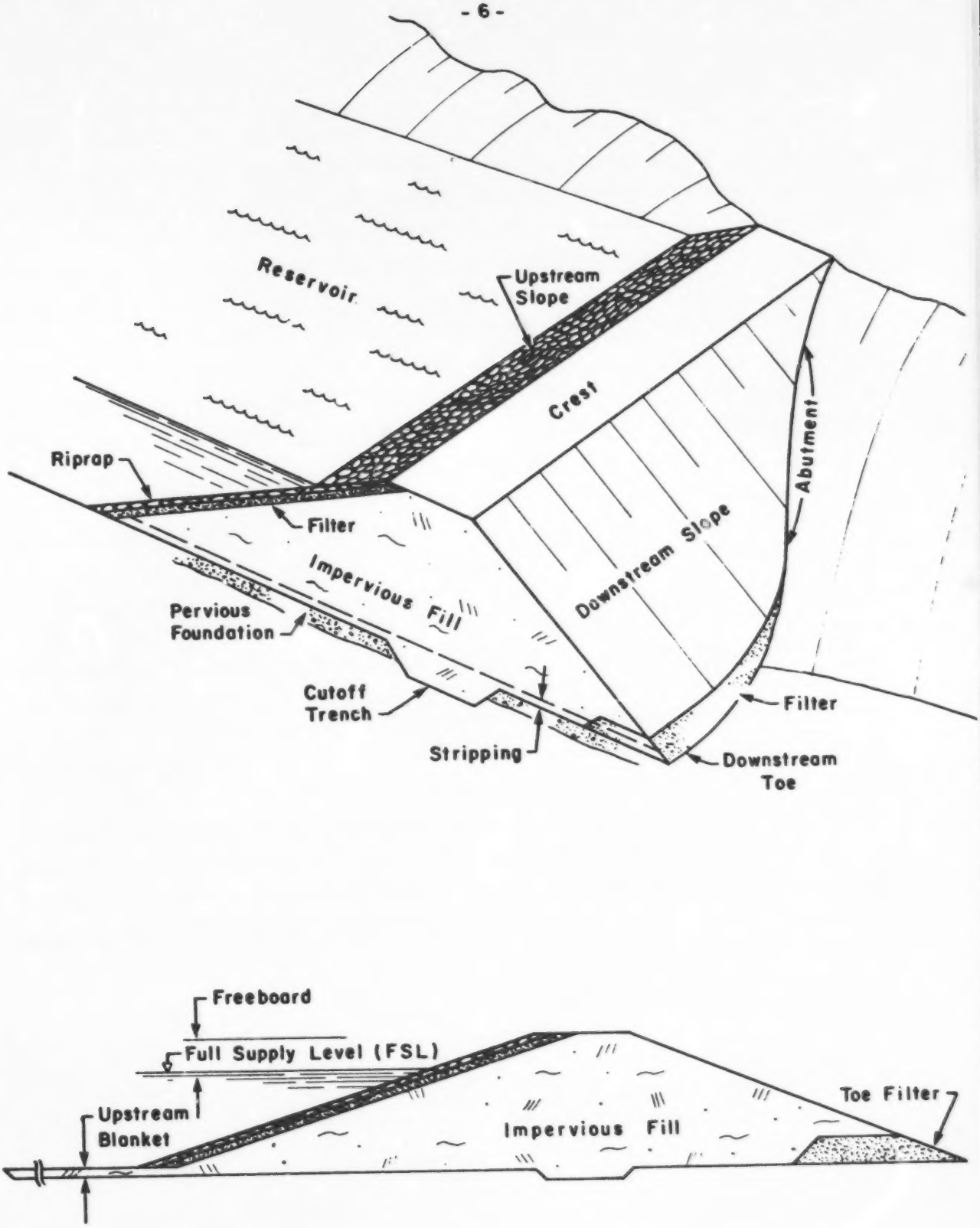



Figure 1 Typical Dam Cross Sections

The top soil from the area which will be covered by the dam should be stripped to ensure good bonding between the dam and the foundation. Most small dams consist of essentially the same type of material throughout the structure. These materials should be clay or a mixture of clay, silt, sand and gravel. Highly plastic clays that shrink and crack badly when dry are unsuitable materials for dam construction. It is important that the embankment material is well compacted especially along the abutment and around any conduits. Inspite of the above measures, dams become saturated with time. Therefore, for most dams, a granular filter should be constructed extending into the dam from the downstream toe. A filter is a layer of sand and gravel which holds back the soil but safely discharges water seeping through a dam. If a dam does not have a filter, then seepage may emerge on the downstream slope decreasing the stability of the embankment and causing internal erosion of the fill.

Upstream slopes of embankments are usually protected from wave erosion by a layer of gravel at least 150 mm thick covered with a layer of rock known as riprap. To provide effective protection, the riprap must be well graded (have a wide range of sizes). If only uniform large rocks are used, the gravel bedding may wash through the voids between the rocks and if only small rocks are used, they may be transported into the reservoir by wave action. The purpose of the gravel layer is to prevent the embankment soil from being washed through the voids between the rocks. If the reservoir is less than 100 m long and the upstream slope of the embankment is at least 3:1, then a layer of coarse well graded gravel slope protection may be sufficient.

## C. MAIN AND EMERGENCY SPILLWAYS

Spillways are designed to pass flood runoff without allowing the reservoir elevation to rise above the dam crest level.

The main spillway releases water when the reservoir rises above full supply level (FSL). The spillway capacity depends to a large extent on the elevation difference between the crest of the spillway and the reservoir level. A clearance, known as freeboard, between FSL and the top of the dam is required so that the design flood can be passed and waves are prevented from washing over the dam. Generally 1 metre of additional freeboard above the design flood level is considered sufficient to prevent overtopping. Common types of spillways include metal or concrete pipes, concrete, timber or gabion chutes and sheetpile weirs.

Emergency spillways are constructed to accommodate floods that exceed the capacity of the main spillway and are usually excavated channels. These spillways are constructed at a higher elevation than FSL and will operate less frequently than the main spillway.

## D. RIPARIAN OUTLETS

Riparian outlets are set at a low level so that water can be released to downstream users. During periods of excessive rainfall, a riparian outlet can be opened to lower the reservoir in anticipation of a flood, thus reducing the chance of overtopping the dam.

## 3. INSPECTION GUIDELINES

### 3.1 General

Early detection of problems can only be made with regular inspections. This will allow dam owners to correct problems before they become so advanced as to impair the safety of the dam. The embankment slopes, crest, toe, abutments, spillways and riparian outlets should be inspected at least annually, and also after heavy rains.

The most common causes of earth dam failures are overtopping of the dam by floods, piping, and embankment slides. These failures are associated with a host of defects such as spillway problems, excessive settlement, seepage, erosion, cracks, tree growth, and rodent burrows.

Erosion failures result from the uncontrolled flow of water from floods, or from continual erosion by waves in the reservoir. Piping failures result from material being transported away from the downstream slope, either internally or from beneath the embankment by concentrated seepage flows. Slides occur in weak or unstable embankments and foundations that are unable to resist forces created by water in the reservoir, seepage pressures, or by the weight of the embankment material. Table I, II, and III provide a summary of erosion, piping, and structural failures indicating various causes and preventative measures.

The following sections deal with the items to look for when conducting an inspection; photographs are provided to show appropriate examples of both good and potentially hazardous conditions. All of the dams shown are located within the province of Alberta.

## TABLE 1 - EROSION FAILURES

| Form | Characteristics | Causes | Preventive Measures |
|---|---|---|---|
| Overtopping | Flow over embankment washing out dam | Inadequate spillway capacity | Spillway to be designed for larger project flood |
| | | Clogging of spillway with debris | Install trash racks where possible or periodically remove debris |
| | | Insufficient freeboard due to settlement of embankment. | Regrade crest to design elevation |
| Wave Erosion | Upstream face eroded | Insufficient riprap or incorrect grading | Place well-graded riprap and filters |
| Toe Erosion | Erosion of embankment toe near spillway or riparian outlet | Spillway or outlet located too close to dam | Discharge water away from the embankment Provide protection. |
| Erosion | Surface runoff eroding downstream face of dam | Poor surface drainage and lack of adequate grass cover on the downstream slope | Provide drains or ensure adequate grass cover on downstream face |

## TABLE II - PIPING FAILURES

| Form | Characteristics | Causes | Preventive Measures |
|---|---|---|---|
| Piping | Progressive internal erosion of material from downstream side of dam or foundation toward upstream eventually leading to a breach in a dam section | Concentrated seepage from downstream slope | Install toe drains or filters |
| | | Seepage along conduits | Grout along conduit to fill voids, replacement of conduit using proper construction techniques |
| | | Leaking conduits | Seal joints. |

TABLE III - SLIDES

| Form | Characteristics | Causes | Preventive Measures |
|---|---|---|---|
| Foundation slide | Sliding of one slope or both slopes with heave of foundation in direction of movement | Soft or weak foundation. | Flatten slope. Construct berms. |
| | | Excess water pressure in foundation | Provide drains, and filters. |
| Upstream slope | Slide in upstream face | Steep slope | Flatten slope. Construct berm. |
| | | Rapid reservoir drawdown | Avoid lowering reservoir by large amount over a short time period. |
| Downstream slope | Slide in downstream face | Steep slope | Flatten slope, construct berms. |
| | | Saturation of slope by seepage | Provide proper drainage by installing toe filters |

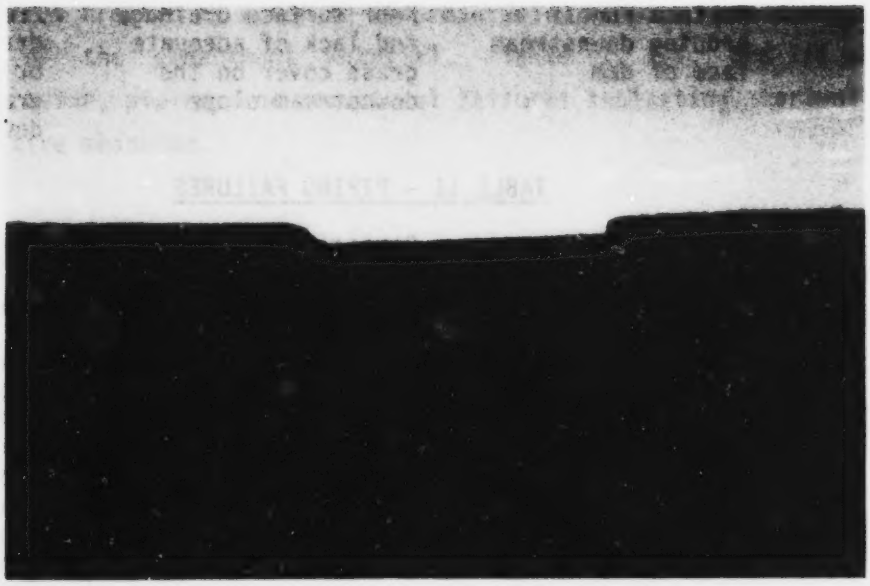


Photo 1 - Breached Dam

## 3.2 SPILLWAYS

When more runoff water enters a reservoir than the spillways are designed to pass, the dam may be overtopped, and the spillway channels may be badly eroded.

Overtopping is the most serious risk to small earth dams and the most common cause of failure. Concrete dams are resistant to damage from overtopping, but earth dams are very vulnerable and will likely breach as shown in Photo 1. Overtopping is a risk which continues throughout the life of the project.

To ensure that a spillway can discharge its designed capacity, it is essential to keep it free of any obstacles. Trees, shrubs, and any debris should be cleared from spillways and spillway approach channels to avoid overtopping of the dam. Installation of trash racks helps to prevent debris from entering the spillway (Photo 2).

A spillway under normal operation should not create or be susceptible to excessive erosion. Scoured areas which may develop adjacent to or downstream of the spillway during periods of high discharge should be regraded promptly and protected with proper bedding material and riprap. Spillway erosion left unattended can lead to a failure of the spillway as shown in Photos 3 and 4.

Concrete spillways must be inspected for cracks or displacements caused by settlement or frost action. Voids created by the settlement of compressible soils located beneath spillways may cause the spillway to crack or displace due to lack of support. When temperatures fall below the freezing point, water located in the soil voids begin to freeze. In frost susceptible soils, such as silt, moisture may move upwards from the underlying soil forming ice lenses several inches thick. These two factors individually or combined cause soil heave. Spillway cracks and displacements may be formed as a result of soil heaving. When a spillway is in operation, water entering an open or unsealed crack can cause erosion of underlying material and heaving of the slabs due to uplift pressure. Large cracks, extending through the concrete should be grouted or sealed.

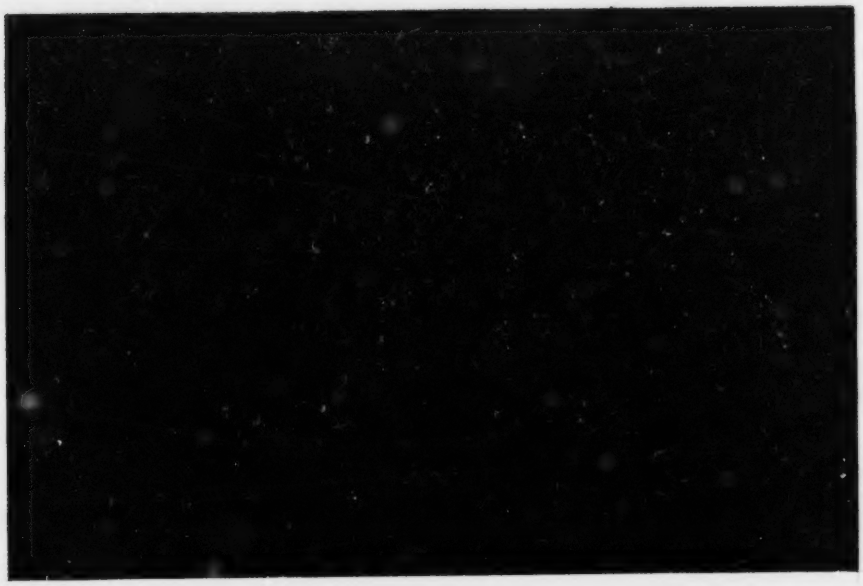


Photo 2 Trash Rack on a Drop Inlet Spillway

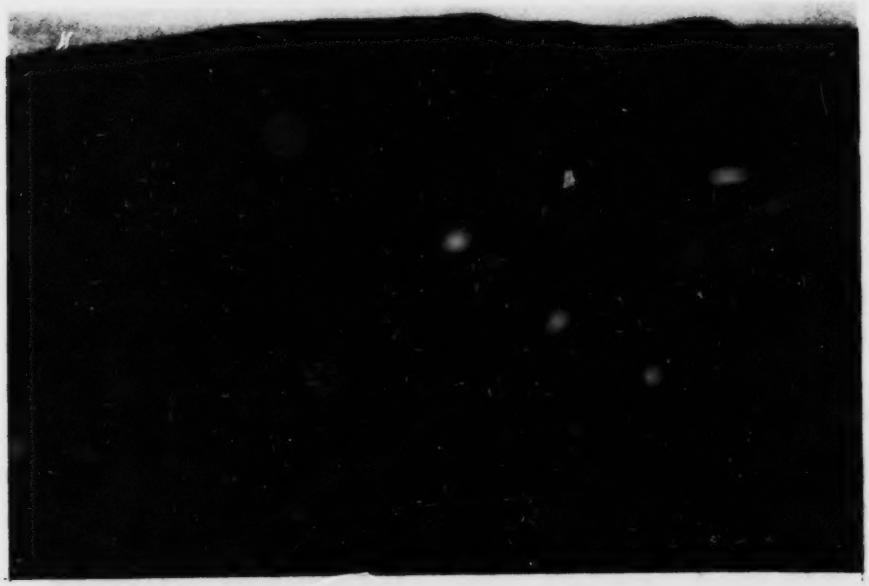


Photo 3 Badly Eroded Spillway

Photo 4 Extensive Erosion at the Spillway Resulted in the Failure of the Control Structure

Freeboard is the vertical distance between the Full Supply Level and the crest of the dam. The amount of freeboard provided varies with the size and location of the reservoir and the dam. Sufficient freeboard should be provided to ensure that waves will not wash over the dam when the reservoir is at FSL. If upon inspection, the reservoir level is approaching the crest elevation, the reservoir level should be lowered to avoid overtopping. Water that begins to overtop a dam will cause rapid and serious erosion, as demonstrated in Photos 5 and 6.

Freeboard is often decreased by settlement of the embankment or foundation, or by blocked spillways. If a dam appears to have settled, as evidenced by a lowering of the crest, a survey may be required for verification. When a dam has settled, additional fill must be placed to restore the freeboard required for the structure.

Photo 5 Overtopping of This Dam Caused Extensive Erosion To the Downstream Slope

Photo 6 Overtopping of this Dam Caused Extensive Erosion to the Downstream Slope

Where safe access is possible, pipe spillways and riparian outlets should be inspected internally to ensure that the pipe barrel is intact. Pipe joints often leak and pipe seams can fail as shown in Photo 7. Both of these cases can be serious and professional advice should be sought.

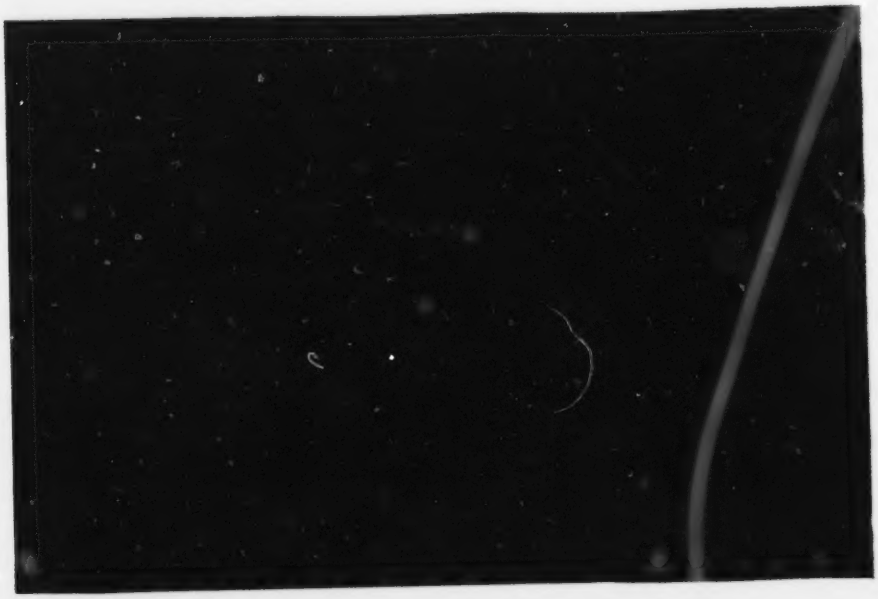


Photo 7 Corrugated Steel Pipe,
Separated seams have exposed the backfill to erosion

## 3.3 SEEPAGE

Ideally, an inspection for seepage should be made when the reservoir level is at or near FSL. Areas to be examined include the downstream slope, downstream toe, abutments, areas near spillways and around and adjacent to outlets. Seepage areas can be identified by wet spots or muddy areas, usually accompanied by the growth of moss on the slope and reeds or cat-tails near the toe. Areas of comparatively thicker, greener vegetation usually indicate a seepage area. The darker area downstream of the embankment toe as shown in Photo 8 is an example of a typical seepage marsh. Placement of stakes around the perimeter of a seepage area provides a good reference in determining if the wet area is remaining constant or increasing in size.

Photo 8 Seepage Marsh Located Immediately Downstream of the Embankment

Embankments and foundations are not impermeable, therefore, small amounts of seepage (not concentrated flows) emerging at the toe or downstream of the embankment is not a serious condition, as long as controlled drainage is provided and ponding is not allowed to occur. Excessive quantities of seepage at the toe warrant an investigation by a professional engineer.

Seepage emerging along the downstream slope (i.e.. above the toe line) tends to saturate the surrounding material. This may lead to an embankment slide, since saturated soils have reduced strength. Both abutments should be examined for seepage along the contact line. Wet spots at the abutments may indicate a poor bond between the embankment and natural ground surface, which essentially becomes a weaker zone of material susceptible to failure. Concentrated seepage is undesirable and if particles of material are being carried by the water a condition known as "piping" may be taking place. If material is being eroded from within the embankment, a piping failure could rapidly develop as shown in Photo 9. Detection of any of the following conditions; seepage at the abutments, seepage along the downstream slope, or piping requires immediate remedial action.

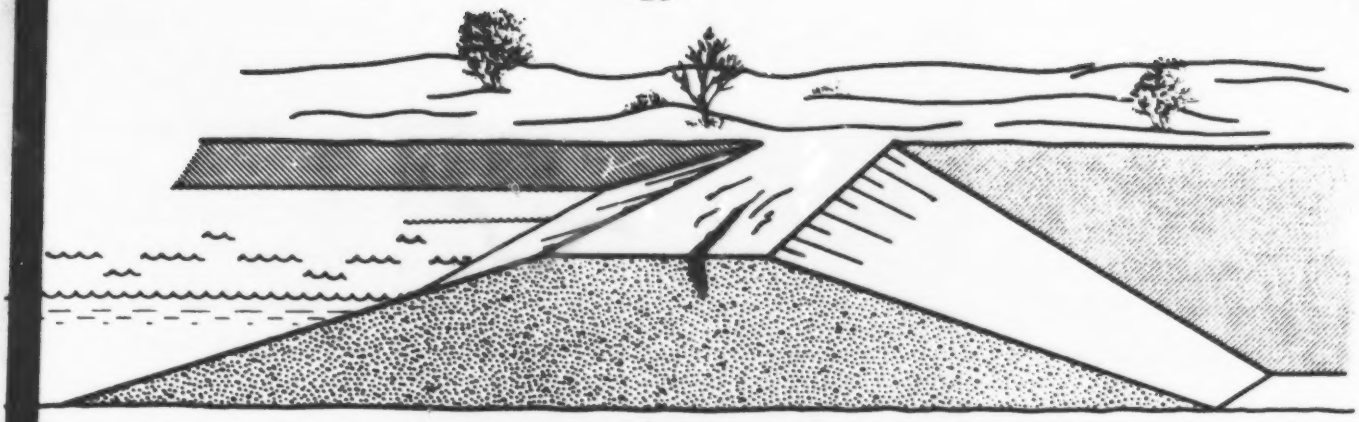
Photo 9 Piping Failure along a Conduit

### 3.4 EMBANKMENT SLIDES

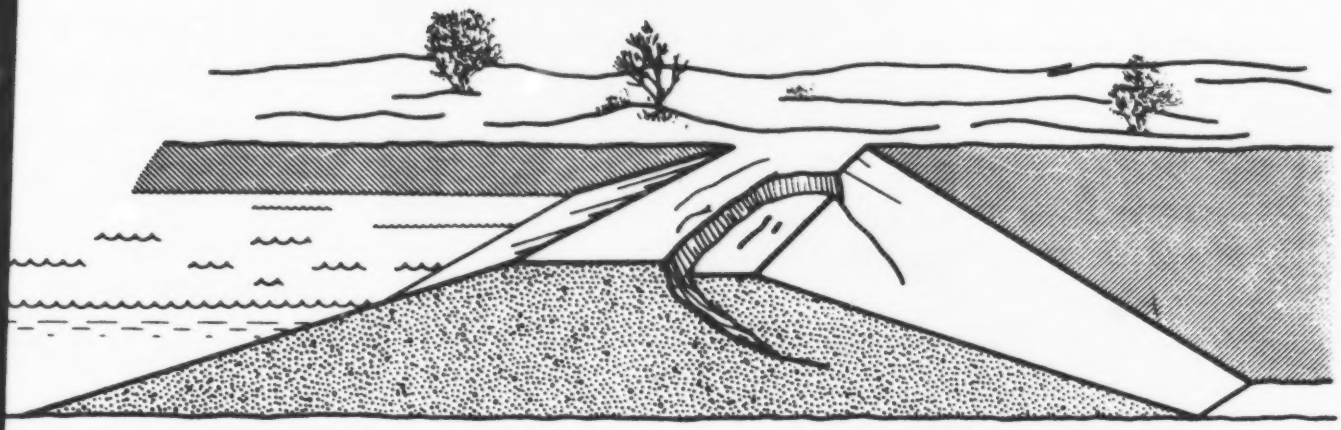
Slides occur when the embankment slopes are too steep or when the embankment material is weakened. Slopes that have developed steeper sections after erosion have reduced stability and are susceptible to slides. The progressive development of an embankment slide is illustrated in Figure 2 and Photo 10. Formation of longitudinal cracks, as illustrated in Photos 11 and 12, normally precede the development of a slide. Longitudinal cracks run parallel to the length of the dam and can form on either slope or on the crest of the dam. If the cracks do not enlarge, the situation may be stabilized but frequent inspections are still required. Once material on one side of a longitudinal crack settles, potential for a slide exists and the dam may be on the verge of a slope failure.

To prevent longitudinal cracks from being filled with surface runoff water and possibly reducing stability of slopes to a failure condition, the crest of a dam should be regraded to a sufficient depth to prevent rain water from filling cracks.

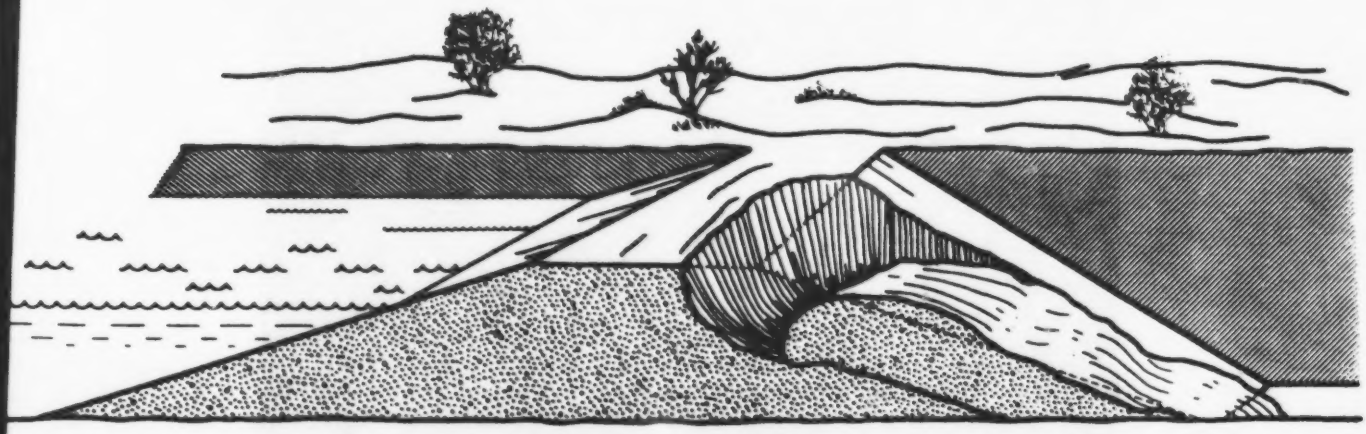
Photo 10 Slide on the Downstream Slope



a) Longitudinal cracks form and runoff water enters



b) Cracks widen and the ground settles on one side of the crack



c) The slope fails

Figure 2 Development of a Slide

Photo 11 Longitudinal Cracks in the Embankment

Photo 12 Longitudinal Crack

## 3.5 CRACKS

Short, isolated cracks appearing on the crest of the dam are usually caused by soil shrinkage and are not a cause for concern. Larger, well defined cracks extending a number of feet in length may lead to further problems. Their dimensions (ie. length, width and depth) should be measured to provide a comparison on the next inspection.

Transverse cracks (figure 3) run perpendicular to the length of the dam and are usually formed due to differential settlements in the foundation or embankment material. Deep cracks located on the crest tend to collect surface runoff and may lead to internal erosion or piping. Deep transverse cracks which extend from the reservoir to the downstream face usually lead to an erosion failure.

An engineer should be consulted to make an assessment and to recommend any necessary repairs if cracks appear anywhere on the dam and are increasing in size or length.

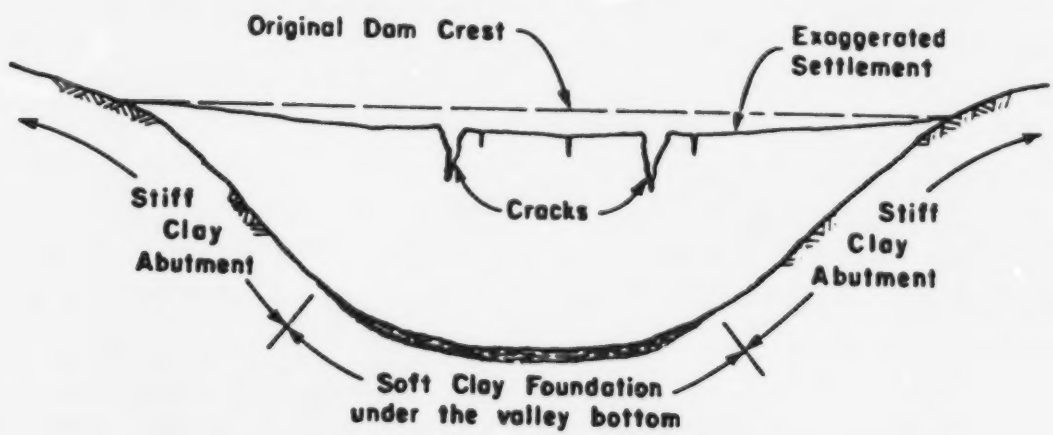



Figure 3 Transverse Cracks Formed by Differential Settlement

## 3.6 EROSION

The upstream slope of the embankment should be examined for any signs of erosion or beaching. Beaching is caused by constant wave action on a slope having inadequate slope protection and is characterized by the presence of vertical sections in the upstream slope.

The riprap should be examined to determine if proper erosion protection is being provided. Displacement of the riprap as shown in Photo 13 exposes the embankment material which is usually susceptible to erosion. The size of riprap used has a bearing on the amount of protection provided. An over abundance of larger rocks allows water to wash between them and carry away the underlying filter and embankment material. Riprap containing mainly smaller stones can be transported into the reservoir, since their weight may be insufficient to withstand the force of larger waves. Properly designed riprap should contain a mixture of large rocks and small stones (i.e. be well graded) to provide adequate protection. Eroded areas in the upstream slope should be upgraded with additional riprap and bedding material to avoid extensive erosion as shown in Photos 14. Such conditions reduce the stability of a dam.

Adequate grass cover must be maintained on downstream slopes to avoid surface erosion of embankment material as shown in Photo 15. Excessive amounts of runoff allowed to flow over downstream slopes, at abutments, or in earthen spillway channels can form erosion gullies. Once an erosion gully is formed, it becomes progressively wider and deeper with each successive rainfall or spring runoff. Continued erosion of this form reduces the stability of a dam, therefore, erosion gullies should be backfilled with properly compacted material. The downstream face should then be grassed or a protective layer of well graded gravel placed on the surface.

Photos 16 and 17 illustrate properly maintained upstream and downstream slopes.

Photo 13 Displaced Riprap

Photo 14 Eroded Upstream Slope

Photo 15 Eroded Downstream Slope

Photo 16 Well Riprapped Upstream Slope

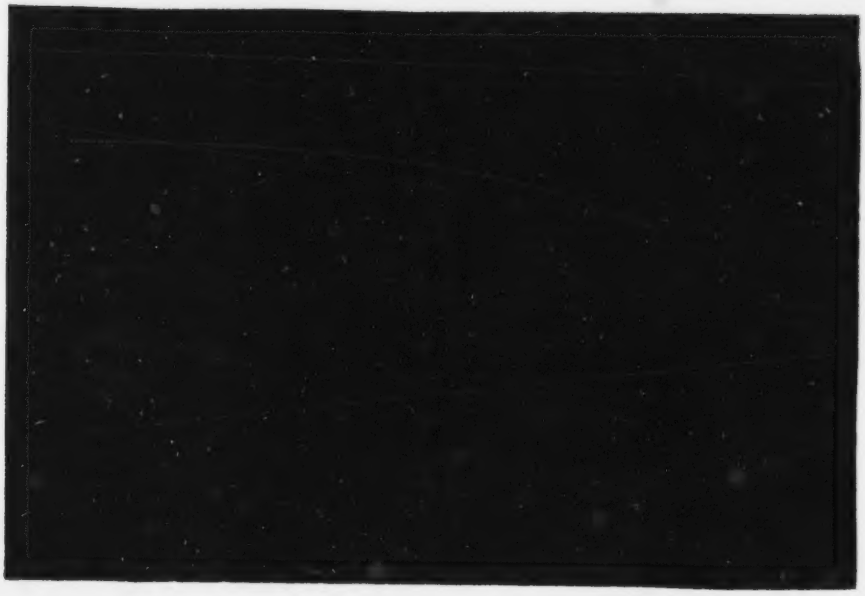


Photo 17 Well Maintained Downstream Slope

## 3.7 RIPARIAN OUTLETS

The crest of the dam, directly above riparian outlet pipes should be examined for any evidence of subsidence. This condition can develop in two ways. First, if a hole or crack formed in the pipe, water flowing through the pipe could enter the hole and erode material. Second, due to poor compaction of material around the pipe, water may be flowing along the outside eroding material in the process. Both cases described are serious problems and a professional engineer should be contacted.

Riparian outlets should be opened periodically to flush out sediments that may be accumulating at the inlet, illustrated by Photo 18, otherwise, the inlet may become plugged.

Riparian outlets cannot be operated when the control shaft is bent or broken as indicated in Photo 19. Control gates should be repaired and always remain operable in case of emergencies.

Photo 18 Blocked Inlet

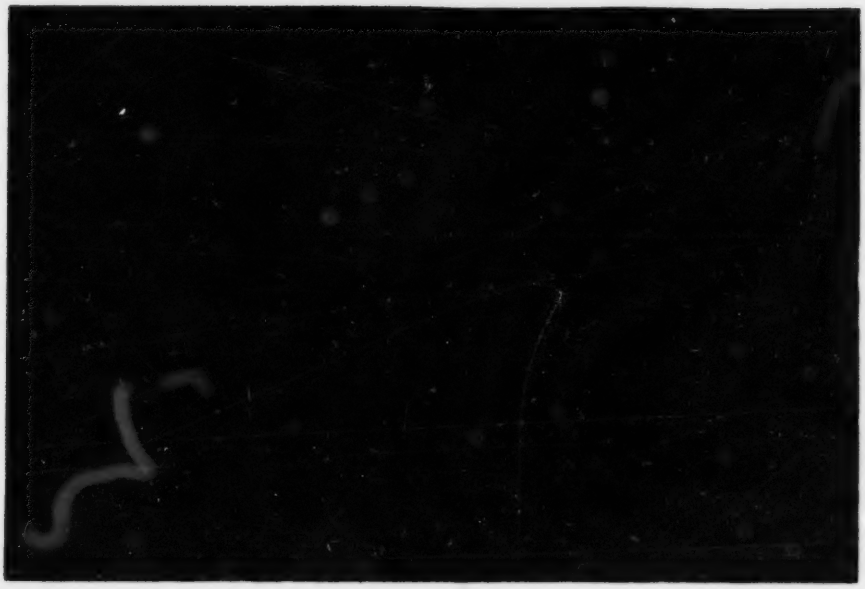


Photo 19 A Bent Control Shaft Makes This Riparian Outlet Inoperable

It should be ensured that erosion and or movements do not cause damage to the outlet end of the riparian outlet (or spillway outlet) as shown in Photo 20. Advice should be obtained and repairs made to remedy these situations.

Photo 20 Riparian Outlet.
Erosion has exposed the last section of pipe
which has become detached adding to the erosion problem

## 3.8 BURROWING ANIMALS

Burrows of animals such as muskrats and ground squirrels have caused piping failures in many small dams. Muskrat burrows are especially hazardous if they extend from the upstream face to a downstream pond as shown in Figure 4. Collapsed burrows close to the crest may also reduce the freeboard.

If a dam has severe problems with burrowing animals they will have to be kept in check by trapping. Any burrows which endanger the dam should be excavated and backfilled with well compacted soil.

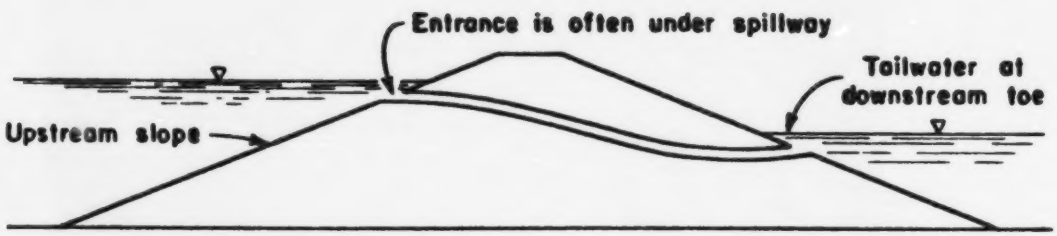



Figure 4 Muskrat Burrow

(by permission John Willey & Sons, Inc. copyright)

## 3.9 VEGETATION

Grass on the downstream slope helps to prevent erosion but trees and dense shrubs are hazards to small dams and should be removed. Among the concerns are:

- the possibility that if a tree on the crest or downstream face blows down a large amount of soil will be displaced and the dam could be breached.
- when the tree dies the decayed roots may provide a path for piping.
- trees may blow down and block the spillway.
- trees and dense shrubs hamper visual inspections.

Photo 21 Tree Growth on the Embankment Slopes is Undesirable.
(Note: Dotted line outlines the embankment)

Photo 22 Shrubs Obscure the Embankment Slopes Making Inspections Difficult.

## 3.10 RESERVOIR

The reservoir banks should be examined for undercutting and erosion. Depending on the size of the reservoir, a bank slide could displace enough water to overtop the dam; smaller slides could block the spillway or reduce the reservoir capacity.

## 3.11 INSPECTION CHECKLIST

Below is a summary of the more important problems associated with small dams and a suggested time of year to inspect to determine if a problem exists.

| Location | Problems | Time |
|---|---|---|
| Upstream slope | slope failure | after rapid drawdown of reservoir |
| | slope protection | after severe winds |
| Crest | settlement | after heavy rains |
| | rutting | autumn |
| | tree and shrub growth | year round |
| Downstream Slope | seepage | during high reservoir levels |
| | rodent burrows | spring and fall |
| | tree growth | year round |
| Downstream Toe | seepage | during high reservoir levels |
| | bulging indicating a slide | after high reservoir levels |
| Spillway | debris blocking spillway or trash racks | before spring runoff and periodically throughout the summer. |
| | erosion | after heavy rains |
| Riparian Conduit | piping | during high reservoir levels |

## 3.12 INSPECTION REPORT

Included for your use is an inspection report form that is used by the Dam Safety Branch during inspections of small dams.

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NOTES

Alberta
ENVIRONMENT

DAM SAFETY BRANCH
INSPECTION REPORT

Project _____ File # _____
Licenced to _____
Location _____ NTS _____
Inspector _____ Date _____
Project Code _____ Date Constructed _____
Engineered by _____
Last Inspected _____ Next Inspection _____
Incomplete _____ Detailed _____ Brief _____

1. **EMBANKMENT**

Dam Height: _____ Capacity: _____ Top Width: _____
Material: _____ Crest Length: _____
U/S SLOPE: _____ Vegetation: _____ Condition: _____
Comments: _____
U/S Protection: _____ Size: _____
Condition: _____
Comments: _____
D/S SLOPE: _____ Vegetation: _____ Condition: _____
Seepage: _____
Comments: _____

2. **OUTLETS**

(a) Conduit

Location: _____ Condition: _____
Type: _____ Size: _____
Inlet: _____
Outlet: _____
Barrel: _____
Well/Gate: _____
D/S Protection: _____
Comments: _____

(b) Spillway

Location: _____ Condition: _____
Type: _____ Capacity: _____
Inlet Channel: _____
Weir/Bed Width: _____
Head Walls: _____
Floor Slab: _____
Chute Walls: _____
Wing Walls: _____
Outlet Channel: _____
Drains: _____

D/S Protection: _____

Comments: _____

_____

(c) Emergency Spillway

Location: _____ Condition: _____

Type: _____ Bed Width: _____

Comments: _____

3. ABUTMENTS

Erosion: _____ Condition: _____

Seepage: _____

Comments: _____

4. RESERVOIR

Use: _____ Level: _____

Source of Supply: _____ Drainage Area: _____

Condition: _____

5. CONDITION D/S OF DAM

Channel Dimension: _____

Vegetation: _____

Habitation: _____

Structures: _____

Tributary to: _____

Comments: _____

6. REPAIRS RECOMMENDED: _____

_____

7. PHOTOGRAPHS: _____

8. LICENCEE: _____

Address: _____

9. PHONE - Work: _____ Home: _____

10. DOES PROJECT COMPLY WITH PLANS? _____ Reason: _____

_____

11. SKETCHES AND ADDITIONAL COMMENTS: _____